UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

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MEMORANDUM FOR: Thomas E. Murley, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 155 , FULL SCALE FLUID MIXING TEST RESULTS IN SUPPORT OF PRESSURIZED THERMAL SHOCK RESOLUTION

This Research Information Letter transmits the results of fluid mixing tests conducted in the full scale Upper Plenum Test Facility (UPTF) located in Mannheim, Federal Republic of Germany. Several experiments were conducted to study mixing between cold Emergency Core Coolant (ECC) and hot primary coolant in the UPTF as part of the 2D/3D International Loss-of-Coolant Accident (LOCA) Research Program. Test reports prepared by Siemens AG are enclosed as Attachments A1 and A2. The UPTF tests and other small scale fluid mixing tests were analyzed by Professor T. Theofanous, University of California, Santa Barbara, CA. The analysis results were reported in several journal articles and reports. Four articles are attached (Attachment B1 through B4) for more detailed information.

1. Regulatory Issue

Reactor vessels are subject to embrittlement from fast neutron fluence. Should an embrittled vessel be subjected to high thermal stress in combination with high pressure, an existing flaw in the vessel wall may develop into a crack from the combination of high tensile stress and low fracture toughness. This concern, known as Pressurized Thermal Shock (PTS), was investigated under Task A-49.

There are two predominant causes of high thermal stress due to overcooling of the vessel wall; steam line rupture and the High Pressure Injection (HPI) of cold Emergency Core Coolant (ECC) into possibly stagnant cold legs following a small break LOCA. In this Research Information Letter (RIL) we address only the latter. Since the most susceptible part of the vessel is the welded part in the belt line region of the vessel, our attention is directed primarily to the degree of thermal mixing in the downcomer below the cold legs.

The magnitude of thermal stress is determined by the degree of mixing between the cold HPI fluid and the hot primary coolant. The most severe case would be for complete stratification to occur between the HPI fluid and the primary coolant. Realistic mixing must be determined to avoid artifically conservative regulatory actions.

NRR requested RES assistance in evaluating fluid mixing as well as other issues as part of Task A-49 (see Attachment C). RES provided sufficient fluid mixing information from a series of small scale tests to help resolve A-49. However, to confirm the uncertainty in extrapolating small scale test results to a full scale PWR, representative tests in a full scale test facility were arranged. Such experiments were performed in UPTF and are reported here.

2. Conclusion

Experiments conducted at test facilities ranging from 1/5 to full scale show that HPI fluid mixes well with primary coolant. Cold ECC warms quickly from mixing occurring primarily in three regions; (1) HPI location; (2) entrance of the cold leg to the vessel; and (3) downcomer region below the cold leg. Primary coolant flows continuously to the mixing regions from the lower downcomer and the lower plenum by natural circulation due to density differences between the cold HPI fluid and the hot primary coolant. The two fluid streams are separated from each other because of a density difference and develop a countercurrent flow pattern. Therefore, the hot primary coolant in the lower part of the downcomer and the lower plenum is able to reach the mixing locations in a continuous manner. This process results in two beneficial effects; the reduced temperature gradient between hot and cold stream and the reduced cool-down rate of the vessel wall. This was illustrated by a UPTF test employing typical PWR HPI (10 kg/sec). The temperature difference between vessel wall and the midplane of the downcomer at the elevation corresponding to the top of the core was less than 10°K, and the cooldown rate was less than 35°K/hr (63°F/hr). This compares to the maximum cooldown rate of 56°K/hr (100°F/hr) typically specified in technical specifications. The full scale UPTF experiments covered an HPI rate of 5 to 70 kg/sec. In all cases, good mixing occurred. As expected, the temperature difference between the wall and the downcomer center increases along with the cooldown rate as the injection rate increases.

The special purpose computer codes REMIX and NEWMIX, developed by Professor Theofanous, predicted the temperature response in the cold leg and downcomer reasonably well. REMIX is used for Westinghouse and Combustion Engineering designs while NEWMIX is used for Babcock and Wilcox designs which employ HPI with high Froude numbers. System codes such as TRAC and RELAP are not applicable to liquid-liquid fluid mixing analysis because they are not designed to handle two liquid streams, only a vapor and a liquid field (two field equations).

3. Regulatory Implications

Full scale UPTF test results are consistent with earlier small scale test results used in resolving Task A-49, and therefore support the resolution previously made under Task A-49.

4. Restriction on Application

The UPTF is a low pressure facility so the initial primary coolant temperature could not be raised to the usual PWR operating temperature, 550°F (228°C). The initial temperature used in the UPTF experiments was 374°F (190°C). However, the thermal stress and the cooldown rate of a typical PWR downcomer wall can be calculated with the codes REMIX and NEWMIX.

5. Unresolved Questions

There is no unresolved question concerning the fluid mixing phenomenon related to the PTS concern. The computer codes REMIX and NEWMIX have been verified with the full scale UPTF test results. Therefore, these codes can be used to estimate the degree of thermal stratification between the HPI fluid and the primary coolant for a given transient.

Eric S. Beckjord, Director
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Attachments:
A1. 2D/3D Program Upper Plenum Test Facility Test No. 1 Fluid-Fluid Mixing Test Quick Look Report
A2. 2D/3D Program Upper Plenum Test Facility Test No. 1 Fluid-Fluid Mixing Test Experimental Data Report
B1. Scaling of Thermal Mixing Phenomena
B2. Mixing of Phenomena of Interest to SBLOCA's
B3. Decay of Buoyancy Driven Stratified Layers With Applicants to PTS: Reactor Predictions
B4. PWR Downcomer Fluid Temperature Transients Due to High Pressure Injection at Stagnated Low Flow
C. Task Action Plan, Pressurized Thermal Shock (Task A-49)